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MEETING FUTURE PEAK ELECTRICAL ENERGY DEMANDS BY MEANS OF ELECTROCHEMICAL STORAGE SYSTEMS

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Translation of "Zur Deckung des zukünftigen Spitzenbedarfs elektrischer Energie mittels elektrochemischer Energiespeicher," Chemie-Ingenieur-Technik, Vol. 46, No. 3, 1974, pp. 95-99.

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16. Abstract

The author investigates the electrical energy crisis in terms of storage equipment. He compares various types in terms of costs, efficiency, maintenance, and raw material reserves. His conclusion is that more study and research is needed before adequate energy storage systems can cover peak load periods.

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MEETING FUTURE PEAK ELECTRICAL ENERGY DEMANDS BY MEANS OF ELECTROCHEMICAL STORAGE SYSTEMS[1]

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Because of a simultaneous inordinate increase in the private sector, the increase in energy needs is coming to an impasse in covering future peak load requirements. The use of suitable electrochemical storage systems could contribute to diminishing the service crisis, to saving fossil fuels for peak load work, to using basic plants more economically and to reduce both environmental concerns and the costs of electrical energy. A critical examination of the characteristics of various secondary battery systems according to technical and economic criteria show that certain high temperature and Redox solution systems could be used to cover peak requirements, but their place in supplying energy will only be determined by future developmental results. /95*

The energy requirements of highly developed industrial countries varies to an extraordinary degree depending on the time of day and the period of the year [1]. The constant increase in energy consumption therefore places the need for covering peak loads on energy supply enterprises to an increasing degree, while heeding ecological and economic points of view. The older thermal power plants and pump storage stations, used at present for this purpose, limited by economic and topographic factors, will be taxed to their highest capacity in the near future [2-4]. From the other hand, the use of gas turbines practiced and adopted for further construction in many countries, presents considerable environmental problems and cannot be considered as a favorable solution from the standpoint of costs [5, 6]. Economic energy production can only be assured by the construction of large power plants (>500 MW) which, however, can only be adapted to small changes in load. Therefore the development of new peak load storage systems for the future becomes more and more

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urgent, if on the one hand, the load capacity of the power plants is to meet consumer demands and if, on the other, fossil fuels are to be saved for peak load plants.

In meeting this challenge electrochemical batteries (EC) offer a number of advantages to be evaluated on the basis of the selective criteria to be established. However, a comparison with the most important properties of pump storage plants and gas turbines in this respect is unavoidable.

The Development of Peak Loads and Demands on EC Batteries /96

The use of electrical energy in West Germany will ostensibly increase four-fold by 1990 (basis 1970: 250 billion kWh; 1990: 970 billion kWh [7]), with private households being the fastest growing sector. According to present prognoses [7] their consumption will increase six-fold in the same period of time, and thus increase from 40% to 60% of final consumption. At the same time this sector is one of the main consumers during peak load periods, so that it is to be expected that peak service requirements will also increase accordingly in the next 20 years.

Figure 1 presents a typical diagram of the electrical energy production in West Germany, as well as its distribution to various energy carriers. Peak load times are found between 8 and 12 a. m. and 4 to 7 p. m. During this time all available pumping storage stations are used after being filled during the night hours of weaker demand. Even current importation from neighboring lands is intensified and individual plants are put into operation. The maximum net load of the entire public supply, which on a yearly average occurs during about 20% of total operating time, is about 1.6 times higher than the minimum load [8]; however, it can reach a service peak 10 times higher for certain groups of consumers.

The energy costs are essentially determined by expenses for transmission, but the latter depends on the peak service to be transmitted [9]. For this reason peak load storage stations should be located in the vicinity of consumer centers as much as possible. This important condition produces some other technical requirements: high energy density, rapid service preparedness and flexibility, high reliability, easy maintenance, and extensive properties favorable to the environment.

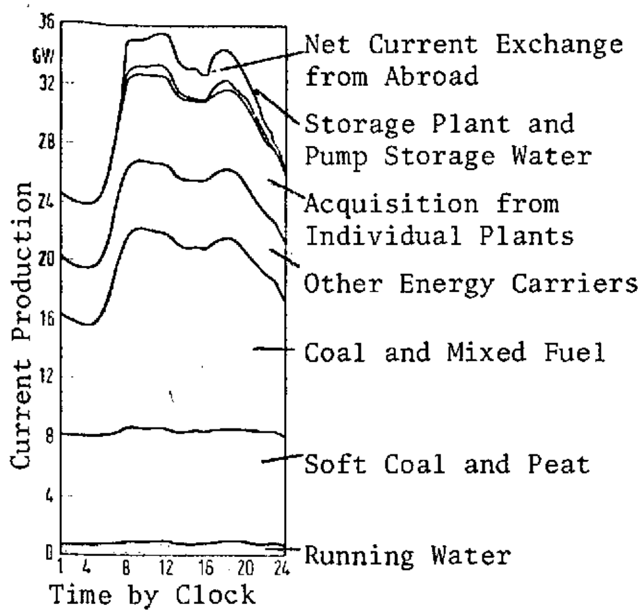

Figure 1. Current Production in West Germany on 15 December 1971 (According to BMWF-W III B2).

On the basis of commercial batteries, electrochemical storage stations correspond in general to most of these criteria. There are still a few other requirements to be met which concern the economy of energy storage and are for the most part based upon the technical properties of this system. They are: investment costs comparable with pump storage stations, a high degree of total efficiency in storage and extraction, long service-life for the most extensive parts of the storage system, and extensive raw material reserves for the active stocks.

The criteria mentioned will be briefly discussed and specified below, since the suitability of the various electrochemical storage systems to be considered will be ascertained with their help.

In reference to volume, the energy density of the system should be at least 30 times greater than that of pump storage plants, which lies at about 0.2 Wh/l water (per 100 m of height difference). The energy density does not only determine the space requirement of the storage system, but also its investment costs to a certain degree. In the first approximation these can be compared with one another for various systems on the basis of the costs of active stock per kilowatt hour by the use of a technological factor.

Service preparedness and flexibility refers particularly to the extraction of stored energy. The system should be able to keep up with high load rates caused by simultaneous input of consumer requirements. A two to five-fold overload should be guaranteed for a short period in order to take over the energy delivery of a basic plant which breaks down. Data about service density (W/l) can serve as a criterion for load capacity, and a value of 100 W/1 should be attainable.

The reliability and ease of maintenance of a storage system can be expressed only with difficulty in technical indices. Their evaluation must be based on an estimate of inherent characteristics on the basis of a knowledge of working methods and system technology. Expenses for maintenance are assumed in the price of the storage energy by way of operating costs.

The criterion of environmental favorability includes every type of effect of the storage system on its environment and concerns, not only the elimination of gases and vapors which may occur in electrochemical systems, e.g., during charging, but also heat release from high temperature systems, the presence of pressure tanks, etc. Maintaining these influences within controlled limits is a basic prerequisite for the erection of peak load storage systems in the vicinity of populated areas and other consumer centers in the private sector.

The investment costs as far as possible should lie in the order of magnitude of those of pump storage stations, which can be assumed at about 600 DM/kW /97
on the average, depending upon the topographic factors and the size of the plant [2, 10]. With a four hour extraction of stored energy, this corresponds to a value of 150 DM/kWh storage capacity. Because of the advantage of lower costs for energy distribution, this value can presumably be raised to about 200 DM/kWh EC capacity.

The degree of efficiency of charging and discharging should also be optimized for economic considerations, since it has a direct effect upon the costs of stored energy both by way of investment costs and multiplied charging energy expenses. Therefore the total degree of efficiency of an electrochemical storage system should amount to at least 68%.

The service-life of the expensive parts of the storage system should be at least 10 years, since it is included in the price of the stored energy by way of the amortization period of the invested capital. At the same time this criterion limits the use of storage systems which present a rather high operational risk because of high working temperatures.

The great capacity for peak energy which must be available in the future requires extremely large amounts of active storage stocks when electrochemical storage systems are used. Thus, the gross current production in 1980 for West Germany may be set at 485 billion kWh [7], which corresponds to an energy consumption of around 78 billion kWh with 16% peak load energy (1971: 25 to 34 GW = 25% of the above peak service). For a daily storage cycle the required total capacity of the storage system would have to amount to 214 million kWh. If, e.g., lead storage cells are used to provide only 10% of this requirement, it would immediately require 0.47 million tons of lead, which is about 16% of the World production for 1971 and about 0.6% of the known reserves of this metal. The raw material reserves for the active stocks should therefore extend over at least 50 years at the current growth rate of consumption.

The Suitability of Electrochemical Storage Systems

On the basis of the above stated criteria, it is possible to measure which electrochemical storage systems can fulfill the prerequisites for peak load supply. Since in many cases this judgment is extremely complex, and since the characteristics differ considerably from each other in state of development, manufacture, and manufacturer, the data are limited to 3 classes of suitability. See Table 1 which provides a presentation of the different electrochemical storage systems which can be used, if necessary, to cover peak loads. Only a few of them have been commercialized up to now, and most of them are in a more or less advanced state of development. Nevertheless, the choice of the systems mentioned should be representative for storage types with the same electrolyte or with comparable electrode combinations. The suitability evaluation [11-19] in Table 1 can be presented as follows:

1). The energy density in Wh/l of all systems mentioned proves to be large enough in comparison to pump storage, where the range extends over values between 40 Wh/l (System 9) and about 400 Wh/l (System 8).

2). The power density in W/l should reach the required value of 100 W/l in all systems except system 6. For a short time the peak values for systems 1, 7 and 8 lie at 500 W/l, and go even above 1,000 W/l for system 3.

TABLE 1. SUITABILITY OF ELECTROCHEMICAL SYSTEMS FOR COVERING PEAK LOADS AS A FUNCTION OF VARIOUS CRITERIA. +: SUITABLE, ○: SUITABLE WITH RESERVATIONS, -: UNSUITABLE. PC = POLYPROPYLENE CARBONATE.

Nr.	Storage system		Energy density [Wh/l]	Power density [W/l]	Degree of efficiency	Investment costs	Service-life	Service, flexibility	Maintenance, reliability	Environmental harmlessness	Raw material reserves
1	Acid electorlyte	Akku change to battery	+	+	+	+	–	+	–	+	–
2	$Pb/H_2SO_4/PbO_2$	Industur. Batt.	+	+	+	–	+	+	–	+	–
3	Alkaline electrolyte	$Cd/KOH/NiOOH$	+	+	+	–	+	+	+	+	–
4		$Fe/KOH/NiOOH$	+	+	+	–	–	+	–	+	○
5	Metal/Air (O_2)	$Zn/KOH/O_2$	+	+	○	–	–	–	–	+	–
6	Organic electrolyte	$Li/PC-LiAlCl_4/CuCl_2$	+	–	+	–	–	–	–	○	+
7	High temperature electrolyte	$Na/Na_2O-Al_2O_3/S$	+	+	+	–	–	+	–	○	+
8		$Li/LiX-MeX/S$	+	+	+	○	–	+	–	○	+
9	Redox solution system	$Cr^{2+/3+}/H_2O/Cr^{6+/3+}$	+	○	+	+	+	+	○	○	+
10	Redox gasification system Electrolysis/fuel cell.	$H_2/H_2O/O_2$	+	+	–	–	–	–	–	○	+

3). The degree of energy efficiency in charging/discharging can be set at ⩾68% for most storage systems under conditions of peak load coverage, i.e., 8 to 10 hours of charging and 4 to 6 hours of discharging. Only system 10 demonstrates a considerably lower degree of efficiency, since the electrolysis of water or the electrochemical decomposition of the electrolysis products H_2 and O_2 proceed with a maximum of 70 or 60% in the fuel cell. Here the total degree of efficiency amounts only to about 42%.

4). The investment costs for almost all of these storage systems come to /98 over the permissible 200 DM/kWh storage capacity, predominantly on the basis of higher costs for the active stocks, their lower energy density, and more extensive production technology. The proportions for systems 1 and 9, where investment costs can be held to 130 to 200 DM/kWh because of more moderate prices for materials and simpler technology, are the most favorable.

5). At 80% discharge of capacity and at 300 cycles per year, the service-life of most systems cannot reach the 10 year limit. Only systems 2, 3 (conditional) and 9 can be expected to produce the satisfactory life anticipations for the expensive parts of the storage system (electrodes and active stocks).

6). Flexibility in power delivery from C/5 to 1C load is guaranteed for all systems with the exception 5, 6 and 10. The cause for the behavior of the latter is found either in their high internal resistance (system 6) or in the insufficient kinetics of the electrochemical decomposition of H_2 or O_2.

7). Reliability and ease of maintenance is only considered (conditionally) satisfactory in the two systems of 3 and 9. However, electronic aids can significantly limit the higher operating costs found in systems requiring intensive maintenance.

8). In general the environmental harmlessness is gauged positive, since the effect on the surroundings of the storage system can be limited by inexpensive methods.

9). In the case of systems 1 to 5 the raw material reserves are unsatisfactory [20]. According to current estimates, reserves for nickel will last for 53 years, lead for 21 years and zinc and cadmium for 18 years. Use of an electrochemical storage system would reduce these supplies even more considerably, since higher rates of increase would have to be presumed.

This evaluation analysis of the individual systems shows that only systems 8 and 9 could give the appearance of being suitable for EC storage systems for meeting peak loads. High temperature systems which work with molten salts as an electrolyte (system 8) still exhibit great technological difficulties (corrosion, problems of insulation) [11], and will probably have an unsatisfactory service--life. Reservations must also be made in respect to investment costs per kWh because of the use of expensive construction materials.

System 9, working with the Redox solution stocks, is also still in the developmental stage. It consists of an arrangement of cells in which the positive and negative charging and discharging electrodes are separated by a semi--permeable membrane (Figure 2). In order to store energy the Redox solution is pumped through the cell with the oxidation or reduction of the dissolved active stocks taking place at the proper electrodes. In order to gain back the stored energy, the solutions are again directed through the cells and the oxidation and reduction reactions reversed. The volume of the Redox solution to be stored can still be considerably reduced by storing part of the Redox stocks in a solid phase. Table 2 contains a selection of various Redox systems which can be considered because of the costs of the active stocks, their solubility and the kinetics of the Redox processes. The state of development of the Redox solution systems does not yet permit any statement about exact technical and economic characteristics. However, an estimate shows that the investment costs for a complete storage plant with a capacity of 100 MWh and a maximum delivery of about 50 MW should lie below 200 DM/kWh storage capacity.

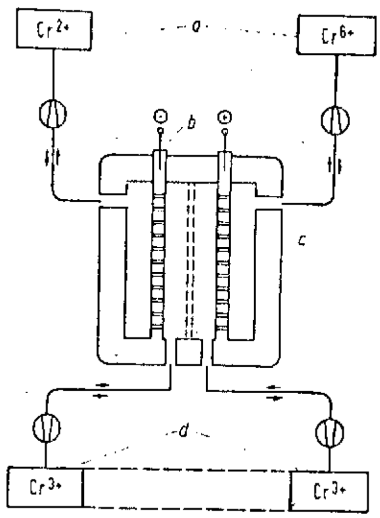

Figure 2. Working Principle of a Redox Cell on the Basis of $Cr^{3+}/Cr^{2+}/Cr^{3+}/Cr^{6+}$. a, Charged solution, b, Charging/Discharging electrodes, c, Semi--permeable membrane, d, Discharged solution.

Conclusion

The use of electrochemical storage systems to cover peak load periods exhibits a series of advantages which makes them particularly suited, along with basic plants, (e.g., nuclear power plants), to operate in the immediate vicinity of the peak load centers. EC storage systems in an organization of module units are easy to adopt to specific load problems in respect to required peak delivery and storage capacity. They avoid the disadvantages of pump storage power plants, which are characterized among other things by very long construction times, high capital investment and high transmission costs; in addition, suitable plant opportunities from the topographic point of view will be about 70% exhausted in Europe by 1980. Furthermore the EC storage systems are not afflicted with the disadvantages of the frequently used gas turbines which require pure, and therefore expensive, fossil fuels, have high maintenance costs (about six times higher than pump storage plants) and produce considerable amounts of exhaust gases. Therefore the further technical development of suitable electrochemical storage systems seems to be the proper way to solve the problems of covering peak loads.

TABLE 2. CHARACTERISTICS OF REDOX SOLUTION SYSTEMS.

Electrochemical reactions (+) Electrode	Electrochemical reactions (−) Electrode	Cell voltage (theor.) [V]	Energy density* [Wh/l]	Cost of active stocks** [DM/kWh]	Remarks
$Fe^{2+} \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} Fe^{3+}$	$Ti^{4+} \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} Ti^{3+}$	0,74	4 (U)	35	Small cell voltage, automatic discharge of Ti^{3+}, high storage volume.
$Cr^{3+} \rightleftharpoons Cr^{6+}$	$Ti^{4+} \rightleftharpoons Ti^{3+}$	1,32	11 (O)	26	Small investment costs, membrane problems.
$Fe^{3+} \rightleftharpoons Fe^{3+}$	$Cr^{3+} \rightleftharpoons Cr^{2+}$	1,19	12 (U)	32	Instability of Cr^{2+}, automatic discharge.
$Cr^{3+} \rightleftharpoons Cr^{6+}$	$Cr^{3+} \rightleftharpoons Cr^{2+}$	1,77	46 (O)	27	1 container: Cr^{3+}, instability of Cr^{2+}, long life of Redox solution.

* With maximum solubility of active stocks as sulfates (t ≈ 25°C); degree of energetic efficiency of charging/discharging = 60% (U), = 68% (O).

**World market prices 1971.

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